Evaluation of Converting the Argo Tunnel ARD Treatment Plant to High Density Sludge

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Abstract
Acid rock drainage from Argo Tunnel is treated by a lime neutralization system owned by the State of Colorado. Due to high operating costs associated with labour and sludge management, the State is considering upgrading this plant to a high density sludge (HDS) system. HDS pilot testing was conducted to evaluate process performance and key design and operating parameters; then an options evaluation study was performed to assess alternatives for modifying the existing system. Pilot testing results indicated that the HDS process would produce approximately one-tenth of the current wet sludge volume and one-fourth of the dewatered sludge volume (that is, a 90% reduction in the amount of sludge to be dewatered and a 75% reduction in the amount requiring off-site disposal). Other benefits of the HDS process include better sludge dewatering, filterability, and potentially good manganese removal at a lower pH. The options evaluation study identified three upgrade alternatives involving a range of new equipment versus retrofitted existing equipment. These alternatives were developed to the conceptual design level to support a comparative analysis based on effectiveness, implementability, and cost. The alternative selected by the State for full-scale construction consists of a adding a new sludge thickener and converting exiting process equipment into the HDS process reactors.

Key Words: acid rock drainage, acid mine drainage, high density sludge, lime treatment

Introduction and Site History
The Argo Tunnel conveys acidic, mining-influenced water – commonly referred to as acid rock drainage (ARD) or acid mine drainage (AMD) – from a number of historical mines to the tunnel portal in Idaho Springs, Colorado, USA. This ARD is treated by a non-HDS lime treatment system located adjacent to the tunnel portal. The existing Argo Tunnel Water Treatment Facility (WTF), owned by the State of Colorado, is subject to what are considered to be high operating costs, particularly for sludge management. The project described in this paper was motivated by those costs and the State's desire to reduce them. The State identified the use of the HDS process as potentially their best option for reducing long-term ARD treatment costs at the Argo Tunnel facility. Two types of studies were conducted to evaluate the feasibility of using the HDS process for treating the Argo Tunnel water: (a) onsite HDS pilot testing to assess treatment effectiveness and establish design and operating parameters, and (b) and evaluation of options for retrofitting the existing plant for HDS.

Some salient events in the site's history are summarized below.
<u>Early History</u>:
- 1859 – Gold was discovered near what is now Idaho Springs, followed by a flood of additional mining claims in the area.
- 1893 to 1910 – The 6.7-km Argo Tunnel was constructed to drain underground workings and facilitate transport of ore from mines to a mill located near the Tunnel portal.
- 1943 – Argo Tunnel operations were discontinued; however, it continues to drain ARD.

Recent History

- 1983 – U.S. Environmental Protection Agency (EPA) added the Argo Tunnel to the National Priorities List as part of the Central City/Clear Creek Superfund Site.
- 1991 – EPA signed the Record of Decision for Operable Unit 3 (Argo Tunnel) requiring, among other things, treatment of the Tunnel discharge.
- 1998 – The Argo Tunnel WTF was completed and began treating Tunnel discharge.
- 2005 – The WTF was converted from using sodium hydroxide to hydrated lime for acid neutralization (because of cost).

Existing Argo Tunnel Water Treatment Facility

The WTF treats Argo Tunnel discharge plus smaller flows from two other nearby sources that are piped to the Argo Tunnel portal (Big Five Tunnel and Virginia Canyon). The WTF influent is characterized by a low pH and concentrations of several metals that are elevated relative to discharge limits (Table 1). It is important for treatment to note that analytical testing of influent samples showed that most of the dissolved iron is in the oxidized, ferric form (Fe[III]).

Table 1. WTF Influent Characteristics and Effluent Limits

Parameter	Units	Influent (2006-09 av)	Discharge limit (30-day av)
Flow	L/s (gpm)	Av: 19 (300) Max (design): 44 (700)	
pH	std units	3.0	6.5-9.0
Aluminum	mg/L	23	
Cadmium	mg/L	0.14	0.003
Copper	mg/L	5.1	0.017
Iron	mg/L	128	15.8
Lead	mg/L	0.03	0.00475
Manganese	mg/L	90	0.8
Zinc	mg/L	45	0.225
Sulphate	mg/L	1,580	

Metals data and limits are for total recoverable metals.

Analyses during pilot testing demonstrated that virtually all of the influent total (unfiltered) metals are in the dissolved form.

The current WTF (Figure 1) is a non-HDS lime treatment system that is similar to conventional lime neutralization except that it uses DensaDeg units (Infilco-Degremont, Richmond, VA, USA) for solids/liquid separation instead of conventional clarifiers. A DensaDeg unit is described by the manufacturer as a high-rate solids contact clarifier/thickener, and it consists of a separate reaction zone followed by a circular clarifier superimposed by a bank of lamella settling tubes. The WTF has two parallel process trains consisting of a rapid mix tank and a DensaDeg unit, followed by a single set of sand filters. Each train has a capacity of 22 L/s (350 gallons per minute [gpm]), for a total plant capacity of 44 L/s (700 gpm). One or both trains can be operated, as needed, to handle a range of ARD flows. Influent ARD first flows to a rapid mix tank where lime slurry is added to achieve a target pH of 10.1. The pH-adjusted fluid then flows to a DensaDeg unit where polymer is added to the reaction zone to enhance flocculation and settling, and then precipitated solids are settled out in the clarifier zone. The clarified supernatant passes through a sand filter and is discharged to the receiving stream. The clarifier underflow (sludge) is dewatered in a plate-and-frame press and then trucked to an off-site landfill for disposal.

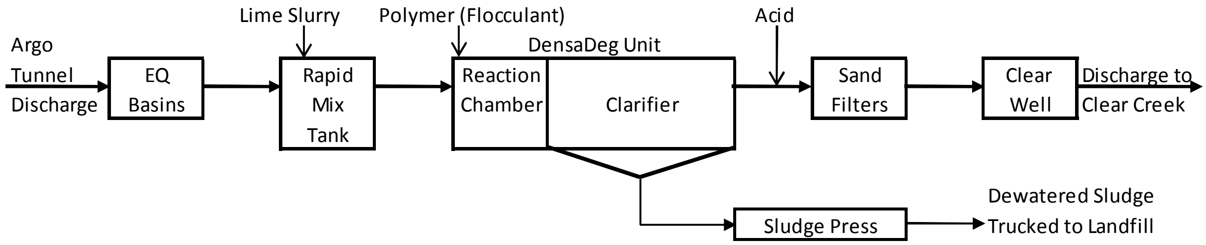

Figure 1. Existing Argo Tunnel WTF configuration

The existing WTF achieves effective ARD treatment, with effluent constituent concentrations consistently in compliance with discharge limitations. WTF issues responsible for motivating the HDS conversion project include:

- Occasional short-term excursions of effluent manganese concentrations above the regulated concentration, while remaining in compliance on a monthly average basis (there is no daily maximum limit for manganese).
- Much higher sludge production (wet sludge at 3-4 percent solids) than originally expected, necessitating installation of a second, larger, sludge press below the original press (the only feasible space available in the building). This increased the dewatering time and eliminated the ability to drop dewatered sludge cake from the original, upper press directly into a roll-off box, thereby making sludge handling more labour-intensive and increasing operating labour costs.
- High cost of trucking and disposing of the dewatered sludge (typically about 15 percent solids) at an off-site landfill.
- Periodic maintenance requirements for draining and cleaning the DensaDeg units to prevent sludge accumulation and possible clogging.

High Density Sludge Process and Pilot Testing

Process description

The HDS process was originally developed by engineers working for Bethlehem Steel Corporation in 1967 (Herman, S.T., personal communication). There are a number of similar configurations designed to densify metals precipitation sludge, but this paper refers specifically to the HDS configuration and nomenclature developed by Bethlehem Steel (e.g., Kostenbader and Haines, 1970) and described in the first patent of the process (Herman et al., 1984). The HDS process is a modification of conventional lime treatment that utilizes a high degree of sludge recycle to an additional small, mixed, sludge conditioning reactor (Reactor A) where lime is mixed with re-circulated sludge solids prior to introducing them to the ARD in a larger, mixed and aerated, neutralization and oxidation reactor (Reactor B) (Figure 2). Advantages of the HDS process relative to conventional lime treatment are that it:

- Produces larger and denser solids particles that settle faster
- Produces thicker settled sludge – typically 20-30 percent solids or greater (versus 1-3 percent solids for conventional lime treatment)
- Yields much lower waste sludge volumes – frequently ≥10 times less
- Produces free-draining sludge that dewaters more quickly and thoroughly – often to >40 percent solids
- Is resistant to scaling – e.g., from gypsum
- Improves filter performance and operability
- Can improves manganese removal at a lower pH (important for this project)

Pilot testing
In December 2009, two continuous-flow HDS pilot plants were operated in parallel onsite at the Argo Tunnel WTF treating Tunnel discharge. The objectives of the pilot study were to evaluate treatment effectiveness and key design and operating parameters needed to establish the basis of design.

The pilot testing results showed that the HDS process provided high removal efficiencies for regulated metals and that effluent concentrations of dissolved metals were consistently below discharge limits (with the exception of manganese, as discussed below). Total (that is, unfiltered) metals concentrations were not always below discharge limits, but calculations indicate that they would be after granular media filtration (which was not part of the pilot study), assuming removal of total suspended solids (TSS) typically achievable via sand filters. Pilot results for manganese indicated that it was effectively removed when a treatment pH near 10 was used, whereas removal was inconsistent at a treatment pH of 9.0-9.5. This was not too surprising, however, since oxygen transfer (required for oxidation of reduced manganese) is quite inefficient in a small, bucket-sized, pilot-scale compared to that in a much deeper, full-scale reactor tank, and full-scale HDS plant operating experience elsewhere has demonstrated that efficient manganese removal can be achieved at treatment pH values in that lower range.

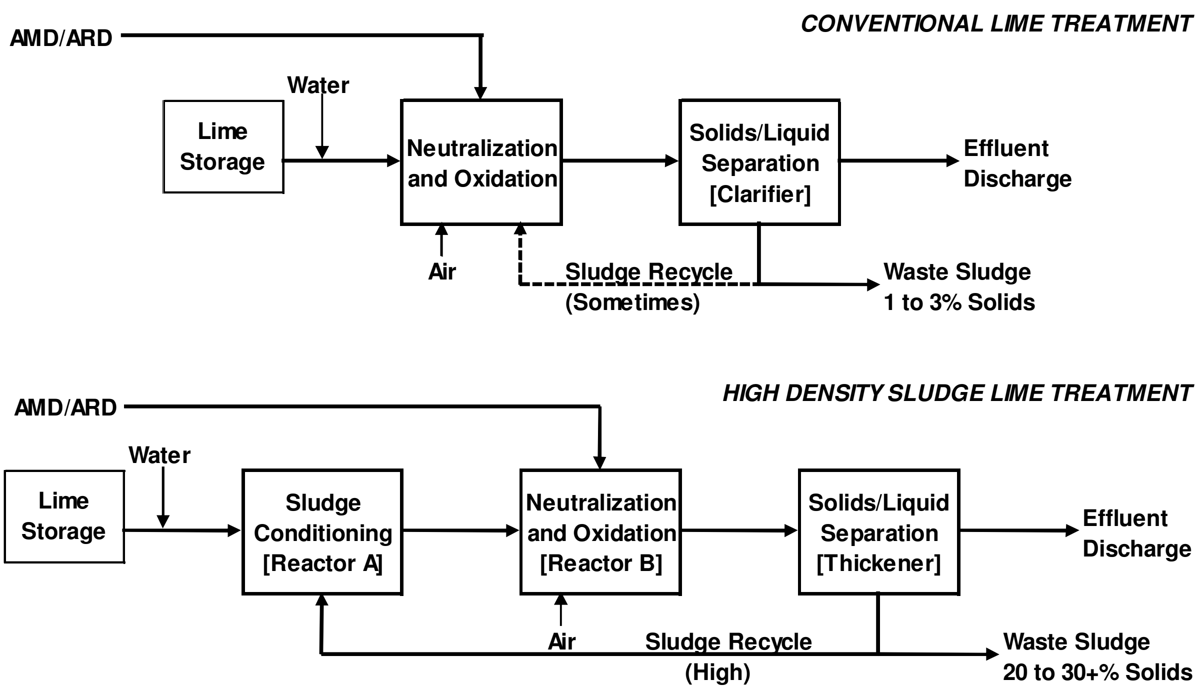

Figure 2. Comparison of the conventional lime treatment and HDS processes (after Herman, 1985)

Because of the high dissolved ferric iron concentration in WTF influent, an additional mixed reactor was used to avoid precipitating iron as freely-nucleating solids in the main Reactor B, leading to lower density sludge. This modification of the basic HDS process was developed by Bethlehem Steel Corporation engineers during pilot testing done for Pennsylvania Electric Company’s Conemaugh Generating Station in 1984 (Herman, 1985). This additional mixed reactor (referred to as a ferric reactor or Reactor B1) is located before the main Reactor B (which is now called B2) in the process train, so that influent ARD flows directly to Reactor B1 and B1 overflows to B2 (Figure 3). The pH in Reactor B1 is maintained at a target of approximately 4.0 by recycling a small amount of sludge to that tank. The bulk of the recycle sludge is still directed to Reactor A, where it is conditioned with lime before overflowing to Reactor B2.

The pilot HDS systems produced thickener underflow sludge that was approximately 22 percent solids, and this sludge could be quickly dewatered in Buchner funnel tests to about 45 percent solids. These results indicate that the HDS process would produce approximately 11% of the current wet sludge volume per unit mass of dry solids (that is, a 89% reduction) and about 25% of the current dewatered sludge volume per unit mass of dry solids (that is, a 75% reduction), assuming 3 and 15 percent solids for wet and dewatered sludge, respectively, generated by the existing WTF. These data show that conversion of the WTF to the HDS process would allow removal of the second (lower) sludge press and result in considerably lower labour, power, and transportation/disposal costs associated with sludge wasting, dewatering, and disposal.

Design basis recommendations from the HDS pilot study are summarized in Table 2.

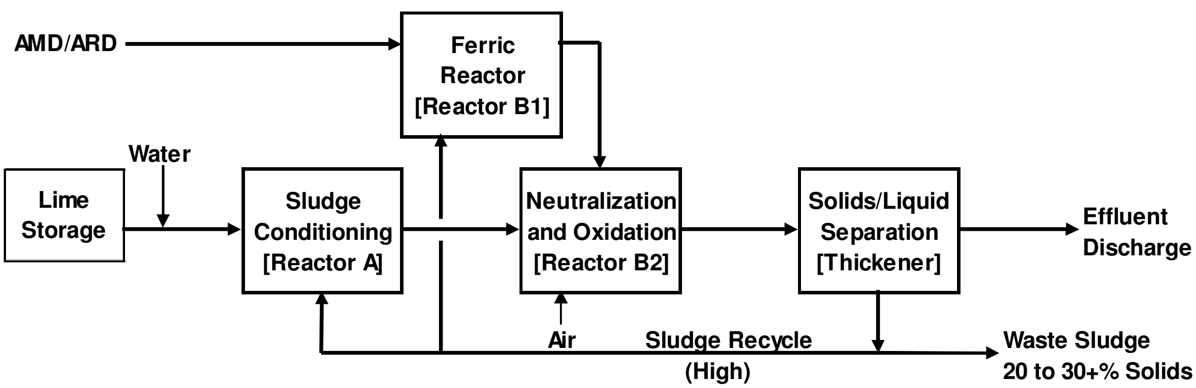

Figure 3. HDS System with ferric reactor (after Herman, 1985)

Options Evaluation

After pilot testing demonstrated favourable results for HDS process treatment of the Argo Tunnel water, an options evaluation was conducted to assess ways in which the existing WTF could be converted to HDS. Three basic options, along with a couple of thickener suboptions, were considered:

- Option 1: Modify DensaDeg units into HDS reactors. This option consists of converting each existing rapid mix tank into an HDS Reactor A, converting each existing DensaDeg unit into HDS Reactors B1 and B2, and constructing a new 15-m (50-ft) diameter thickener in accordance with either Suboption 1a or 1b.
  - Suboption 1a: Construct a new thickener vessel and re-use existing thickener mechanism and bridge owned by the State of Colorado (located at another old mining site). This suboption involves moving the equipment from the Summitville site, and modifying it to fit the new thickener vessel constructed at the Argo Tunnel WTF.
  - Suboption 1b: Construct a new thickener vessel, mechanism, and bridge. A new thickener mechanism and bridge would be procured to go with the new thickener vessel and foundation.
- Option 2: Replace DensaDeg units with new HDS reactors. This option consists of removing the rapid mix tanks and DensaDegs, building a single set of new HDS reactors (Reactors A, B1, and B2), and constructing a new 15-m (50-ft) diameter thickener.
  - Suboption 2a: Same thickener approach as 1a.
  - Suboption 2b: Same thickener approach as 1b.
- Option 3: Modify DensaDegs for limited sludge recycle. This is a low-cost option that involves recycling sludge to the extent possible in the existing DensaDegs, within constraints exerted by

the small size of the clarifier section. This option would not produce high density sludge and would only provide modest improvements in sludge quality.

For each option, equipment items and work elements were identified, conceptual designs were developed, capital and operating costs were estimated, and net present value (NPV) costs were calculated. In addition, operating cost savings compared to actual current costs for operations and maintenance (O&M) and the payback period were estimated for each option. Then, a comparative analysis of the options was performed based on the criteria of effectiveness, implementability, and cost.

Table 2. HDS Process Design and Operating Data

Parameter	Units	Recommended Value
Lime demand	g/L	0.50-0.58
Solids formed, pH 4	g/L	0.27
Solids formed, pH 10	g/L	0.67
Ferric reactor (Reactor B1)		required
Reactor B1 pH	std units	3.7-4.0
Treatment pH (Reactor B2)	std units	9-10[a]
Solids Recycle Ratio	wt ratio	20-30:1
Reactor A hydraulic retention time (HRT)	minute	1-3
Reactor B1 HRT	minute	>4
Reactor B2 HRT	minute	30
Thickener diameter	m (ft)	15 (50)
Polymer flocculant		required[b]
Polymer type		Ciba Magnafloc® 338[c]
Polymer dose	mg/L	3[d]
Wet sludge solids content	wt %	22
Dewatered sludge solids content	wt %	45+
Dry solids specific gravity		3.5
Granular media filtration		required

[a] Recommend designing to accommodate pH 10, but conducting full-scale trials lowering pH to 9.5, then 9.0, while evaluating manganese removal, to determine optimum treatment pH.

[b] Required to accelerate settling and clarification and reduce thickener size, to fit within tight site area constraints.

[c] A high molecular weight, low anionic charge polyacrylamide. Ciba is now owned by BASF and their polymer naming scheme has changed.

[d] 3 mg/L was effective in pilot testing, but dose should be optimized at full-scale.

Some of the more prominent comments on effectiveness and implementability are as follows.

- Options 1 and 2 are superior to the non-HDS Option 3 in terms of effectiveness, including better manganese removal, sludge quality, and sludge volume reduction, as well as lower overall operations labour and cost.
- Option 1 is considered slightly more reliable than Option 2 because it has reactor redundancy (2 trains).

- Option 2 has custom-sized and -configured reactors, and is slightly less complex to operate, having only one train, than Option 1.
- There are slightly more implementation uncertainties with Option 1 than Option 2, because it involves retro-fitting existing equipment.
- There are also more uncertainties with Suboptions 1a and 2a (compared to 1b and 2b) associated with moving, modifying, and the need for rehabilitation of the Summitville thickener equipment.
- Option 3 provides only marginal improvements over the existing system, but is readily implementable and low-cost.

The cost comparison is summarized in Table 3.

Table 3. Cost Estimate for WTF Conversion Options

Option	**Description**	**Capital Cost**	**Annual O&M Cost[a]**	**30-year NPV Total Cost[b]**	**Payback Period [year]**
1a	Convert existing units into HDS reactors, new thickener, re-use mechanism and bridge	1.76	0.805	14.1	12
1b	Convert existing units into HDS reactors, new thickener, new mechanism and bridge	2.11	0.805	14.5	16
2a	New HDS reactors and thickener, re-use mechanism and bridge	2.60	0.815[c]	15.1	25
2b	New HDS reactors, thickener, mechanism, and bridge	2.82	0.815[c]	15.4	29
3	Modify DensaDegs for limited sludge recycle	0.370	0.952	15.0	10

Cost units: million U.S. dollars (USD) (2010)

[a] Current O&M cost for existing WTF ~$1 million (USD)

[b] Interest rate used for NPV = 5%

[c] O&M costs for Option 2 are slightly higher than for Option 1 because the former requires full-time operation of larger mixers, whereas the latter allows one train to be shut down during low-flow periods.

Option Selection and Implementation

Option 1b was chosen by the State of Colorado, and design is now underway. Retrofit design always presents more challenges than new design. Some of the design challenges encountered include:

- Retrofitting the existing rapid mix tanks into correctly-sized, -configured, and -positioned HDS A-Reactors. This has proven to be impractical, and new A Reactor tanks will be constructed.
- Fitting the new thickener within the small area available between the existing WTF building and the property line. This requires construction of a retaining wall.
- Creating the appropriate hydraulic grade line and pipe slopes between the B2 Reactors, thickener, and filters (considering that flow currently goes directly from the DensaDegs to the filters). The new reactor sidewalls will be raised slightly.
- Planning the construction sequence to maintain continuous, uninterrupted treatment in one process train during construction.

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Acronyms

AMD	acid mine drainage
ARD	acid rock drainage
EPA	U.S. Environmental Protection Agency
gpm	gallon per minute
HDS	high density sludge (treatment process)
HRT	hydraulic retention time
NPV	net present value
O&M	operations and maintenance
TSS	total suspended solids
USD	U.S. dollars
WTF	(Argo Tunnel) Water Treatment Facility